

# Chapter 18

## The Interstellar Medium



# Units of Chapter 18

**18.1 Interstellar Matter**

**18.2 Emission Nebulae**

**18.3 Dark Dust Clouds**

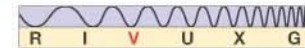
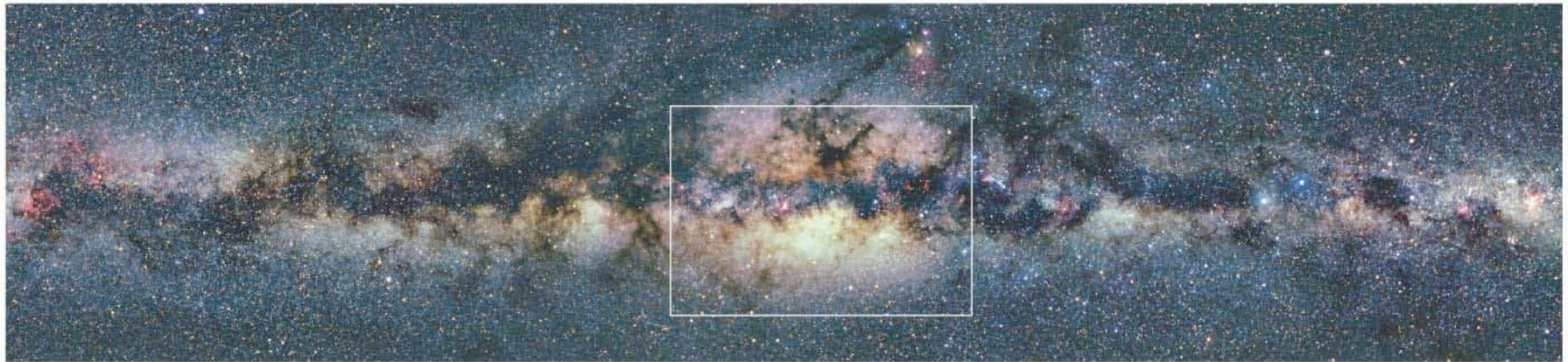
**Ultraviolet Astronomy and the “Local Bubble”**

**18.4 21-Centimeter Radiation**

**18.5 Interstellar Molecules**

# 18.1 Interstellar Matter

A wide-angle view of the Milky Way—the dark regions are **dust clouds**, blocking light from the stars beyond:



# 18.1 Interstellar Matter

**The interstellar medium consists of gas and dust.**

**Gas** is atoms and small molecules, mostly hydrogen and helium, with less than a percent other elements. (But most molecules contain these elements, because H and He do not form molecules easily.)

Three ways to observe gas to be discussed (see notes that accompany slides at course web site)

Neutral hydrogen 21 cm. line (radio),

Emission lines from atoms in hot gas clouds (visible), and

Spectral lines from interstellar molecules within cold dark clouds.

# Interstellar matter: dust

**Dust** is more like soot or smoke; larger clumps of particles.

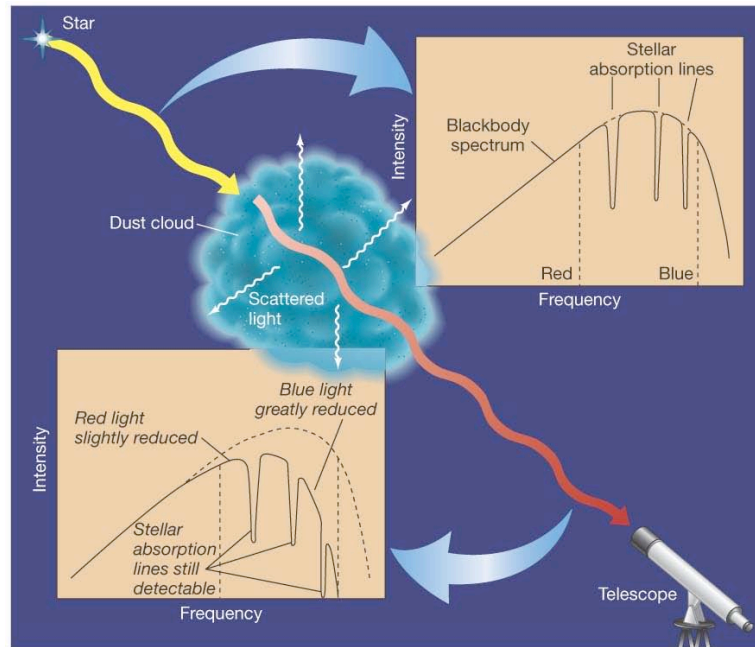
Dust *absorbs* light (“extinction,” dark clouds); and *reddens* light that gets through (reddens = changes *shape* of spectrum, which is how color is defined).

Reddening can interfere with measurement of continuous spectra of stars and galaxies, requiring a correction; but spectral lines do not “shift,” as in Doppler “redshift.”

Dust also emits its own light, a continuous spectrum, which always peaks somewhere in the infrared part of the spectrum, depending on the dust’s temperature.

# 18.1 Interstellar Matter

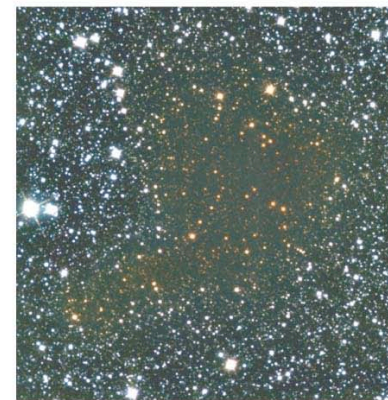
This image illustrates how reddening works. On the right, the upper image was made using visible light; the lower was made using infrared. The dust cloud shows up as a “dark cloud” because it is also absorbing (besides reddening) light from stars behind it.



(a)



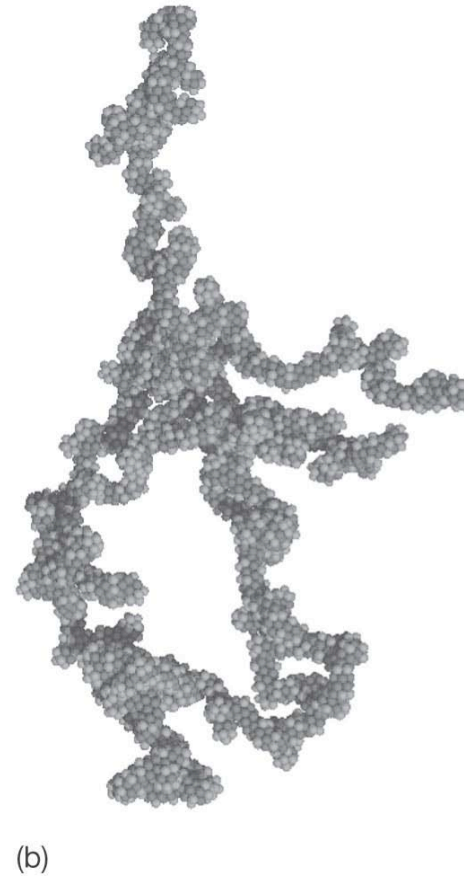
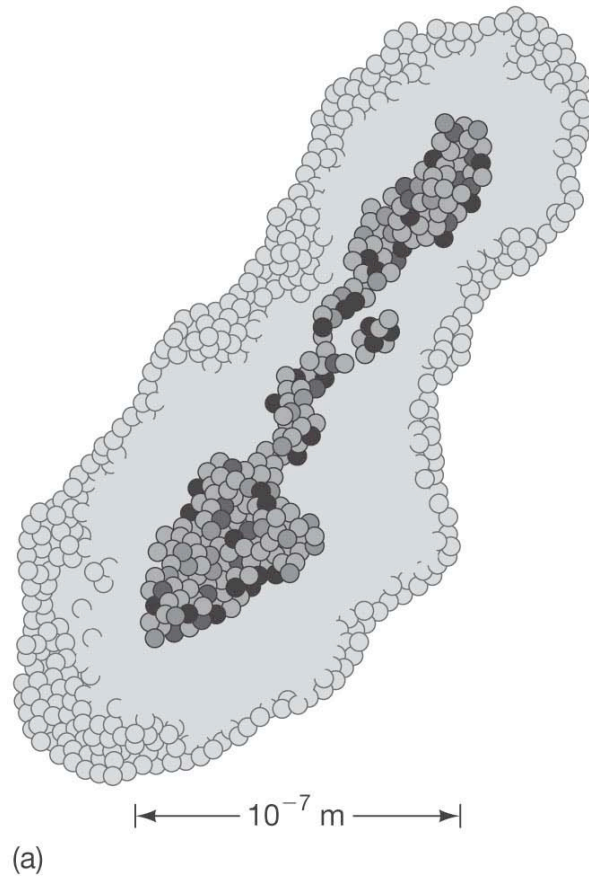
(b)



(c)

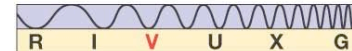
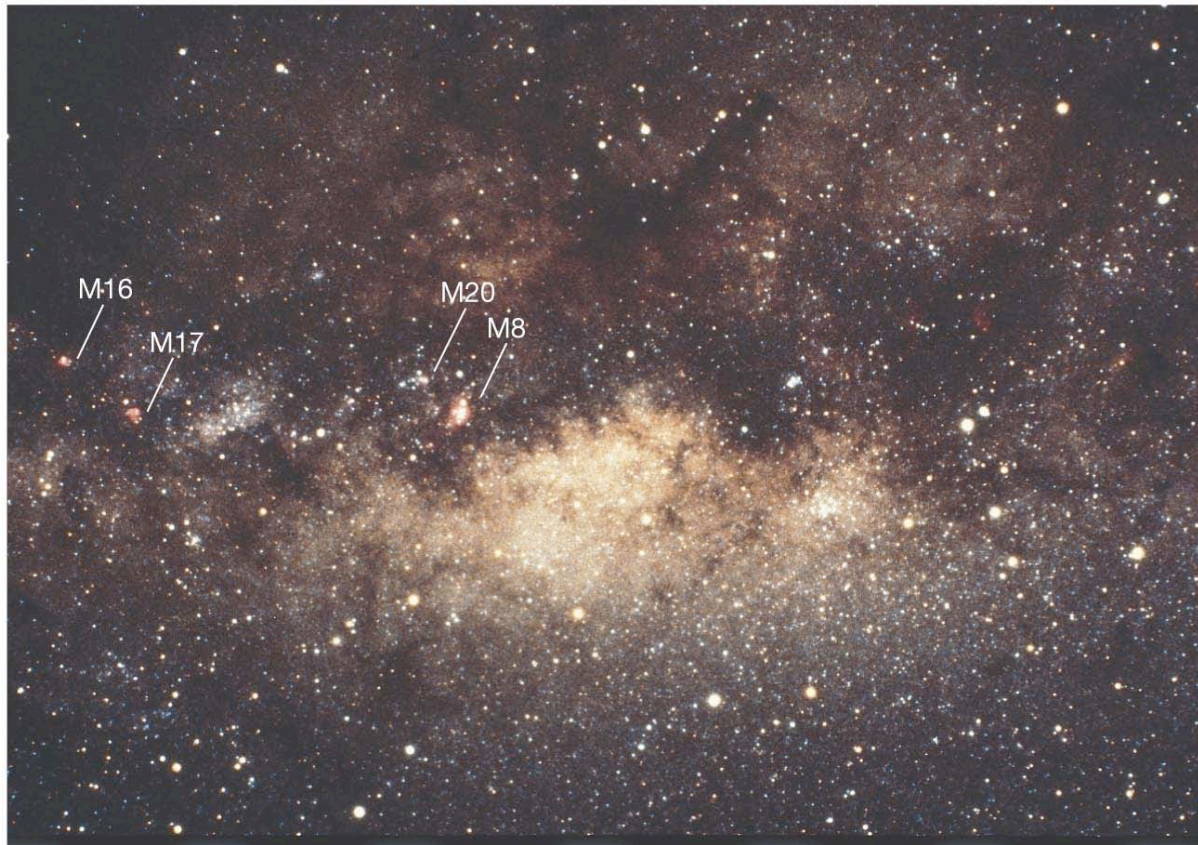
# 18.1 Interstellar Matter

**Interstellar dust grains are complex in shape (left); on the right is the result of computer modeling of how a dust grain might grow:**



# 18.2 Emission Nebulae

Here is a view of the central portion of the picture on the first slide, with several “nebulae” indicated. The bright nebulae are clouds of gas that have been heated and ionized by the UV radiation of hot young stars that recently formed within them. A hot thin gas radiates emission lines, which is what most of this light represents.





# 18.2 Emission Nebulae

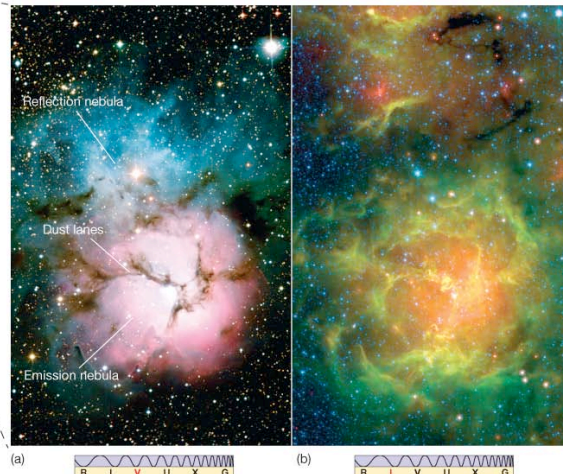
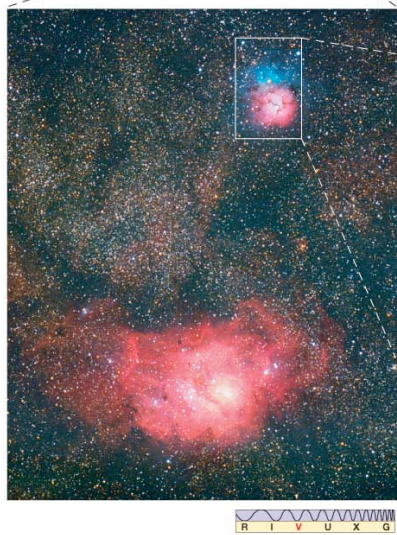
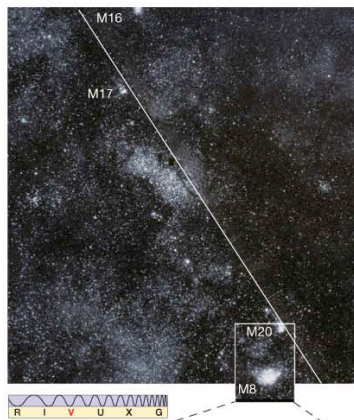
“Nebula” is a general term used for fuzzy objects in the sky:

**Dark nebula:** Dust cloud

**Emission nebula:** Glows, due to emission lines from gas heated by hot young stars (a way to find where stars have recently formed).

Emission nebulae generally glow red—this is the  $H_{\alpha}$  line of hydrogen. But others shine primarily in green light from an ionized oxygen line.

The dark dust lanes visible in these images are part of the nebula, and are *not* due to intervening clouds.

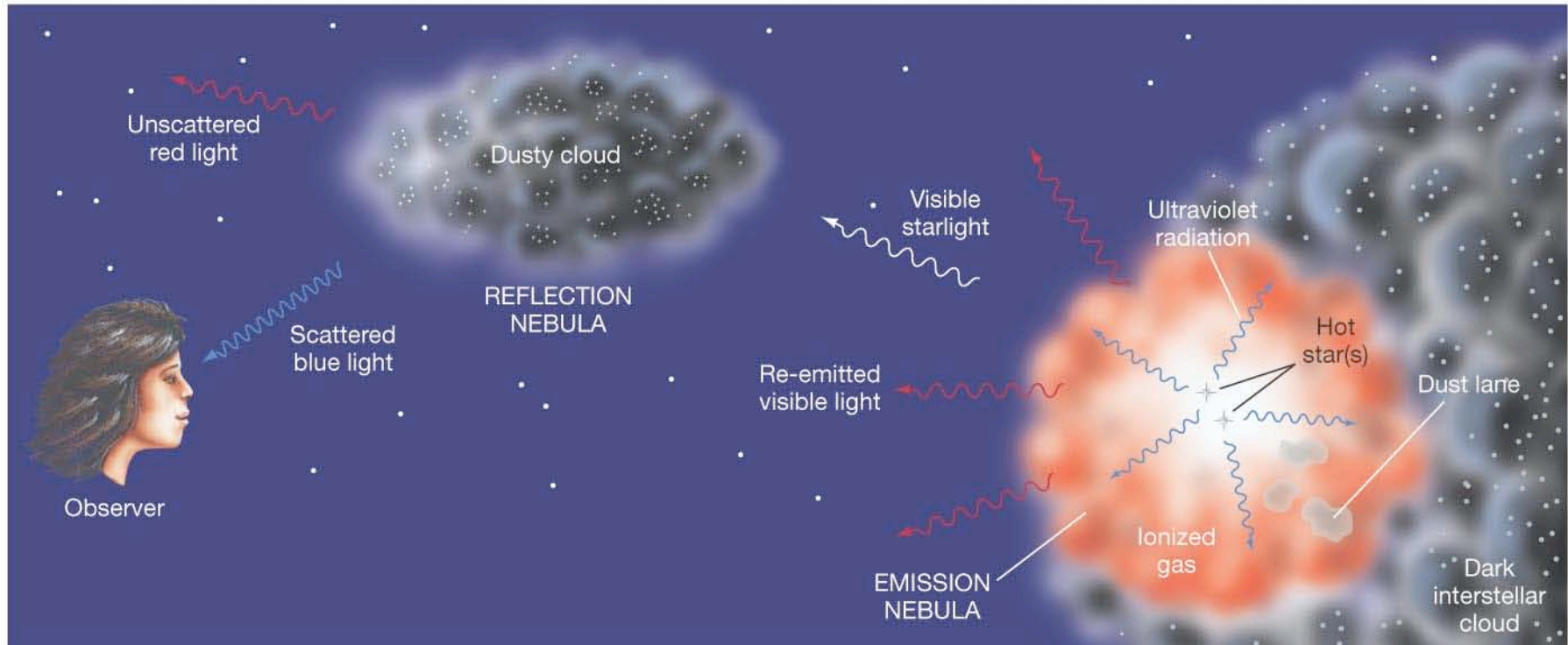


Images are zoom-in on emission nebulae M8 and M20 (seen in previous slide as bright spots along the Milky Way).

**Bottom left:** appearance of both nebulae in visible, mostly emission lines; **center,** zoom on M20 in visible light, showing dark lanes of dust that are absorbing other light from the cloud; **right,** image in infrared light, showing the warm dust grains where the dark lanes were in the visible light image.

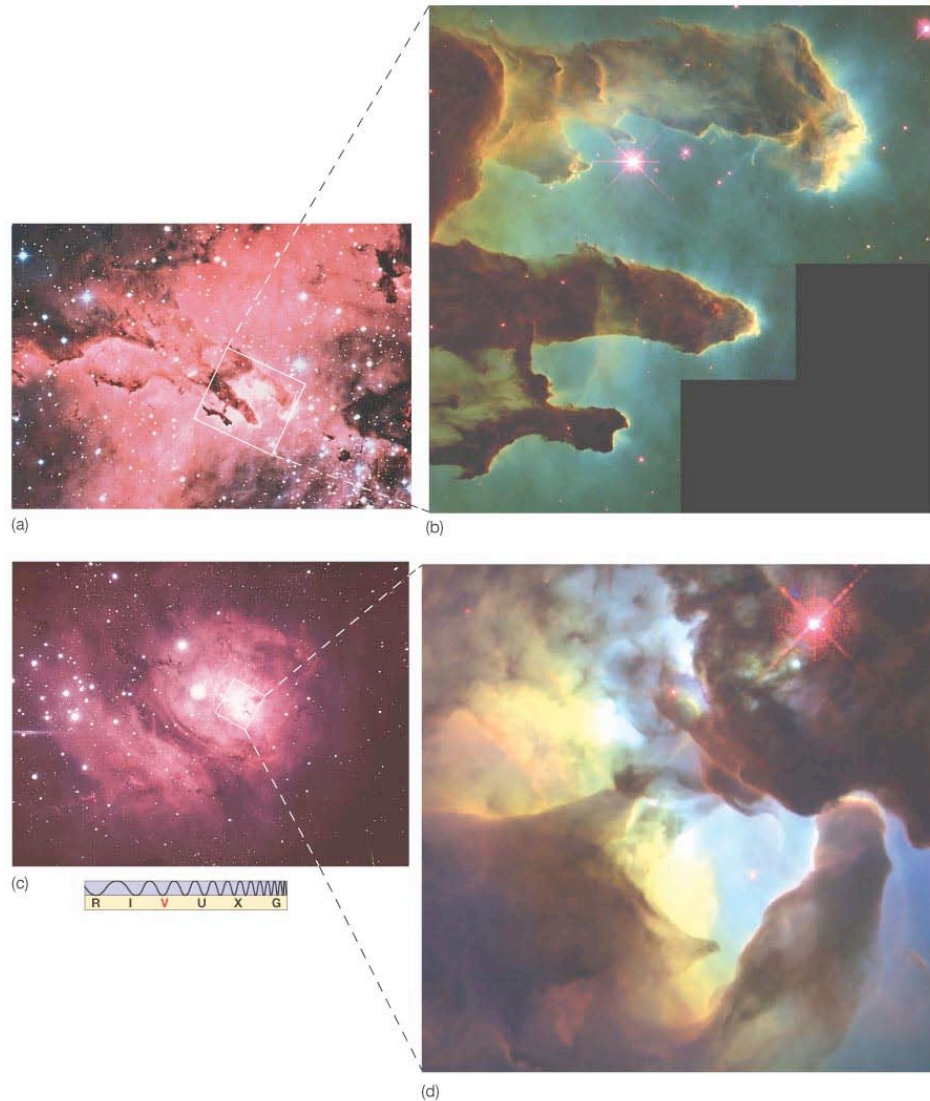
# 18.2 Emission Nebulae

## How nebulae work:



# 18.2 Emission Nebulae

There is a strong interaction between the nebula and the stars within it; the fuzzy areas near the pillars are due to photoevaporation:

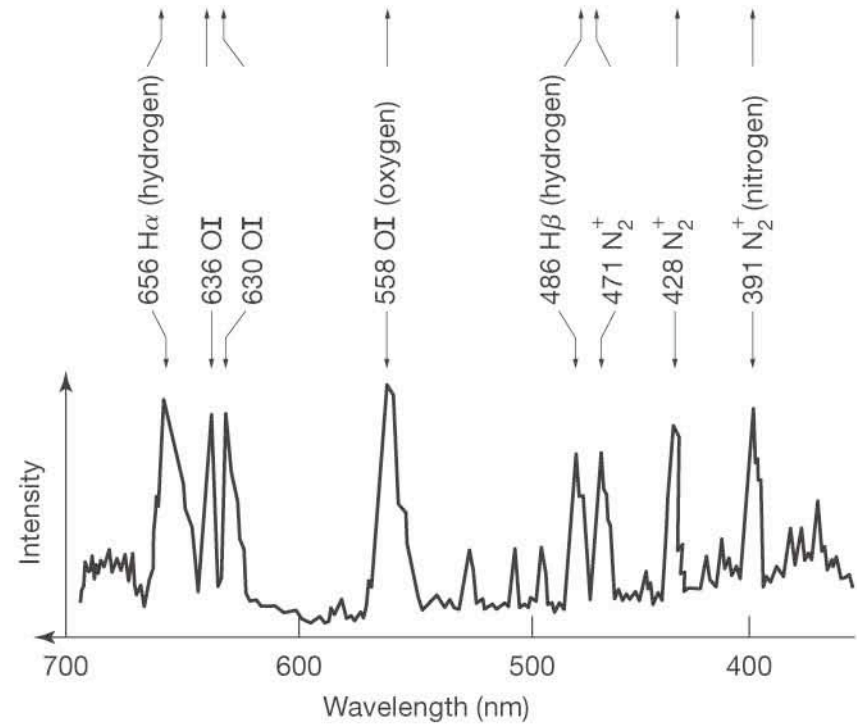
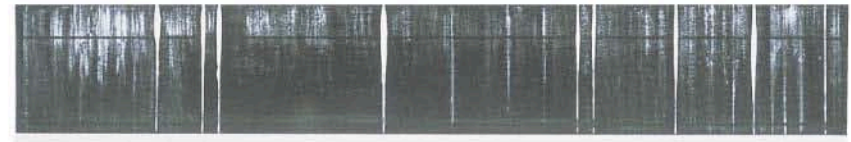
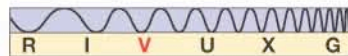


# 18.2 Emission Nebulae

Emission nebulae are made of hot, thin gas, which exhibits distinct emission lines:



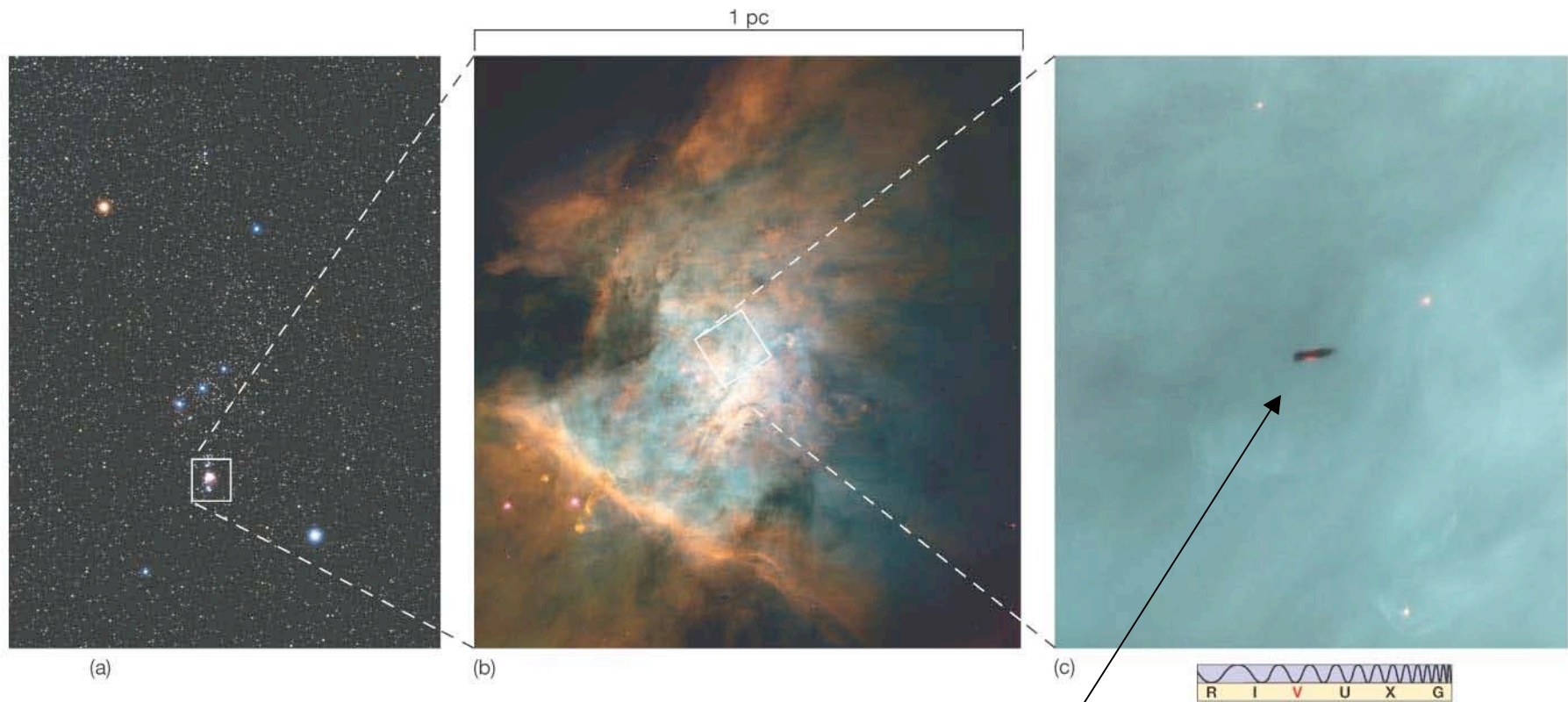
(a)



(b)

# 18.2 Emission Nebulae

An electron transition in oxygen is responsible for the greenish color in the Orion nebula:



**A protoplanetary disk seen edge-on, with a young star at its center.**

# 18.3 Dark Dust Clouds

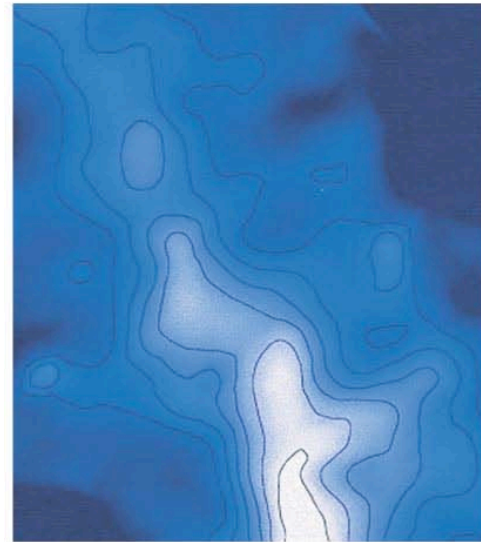
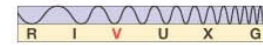
Average temperature of dark dust clouds is a few tens of kelvins.

They are cold because they contain no massive stars (yet)

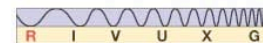
These clouds absorb visible light (top) and emit radio wavelengths (bottom):



(a)

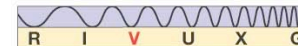
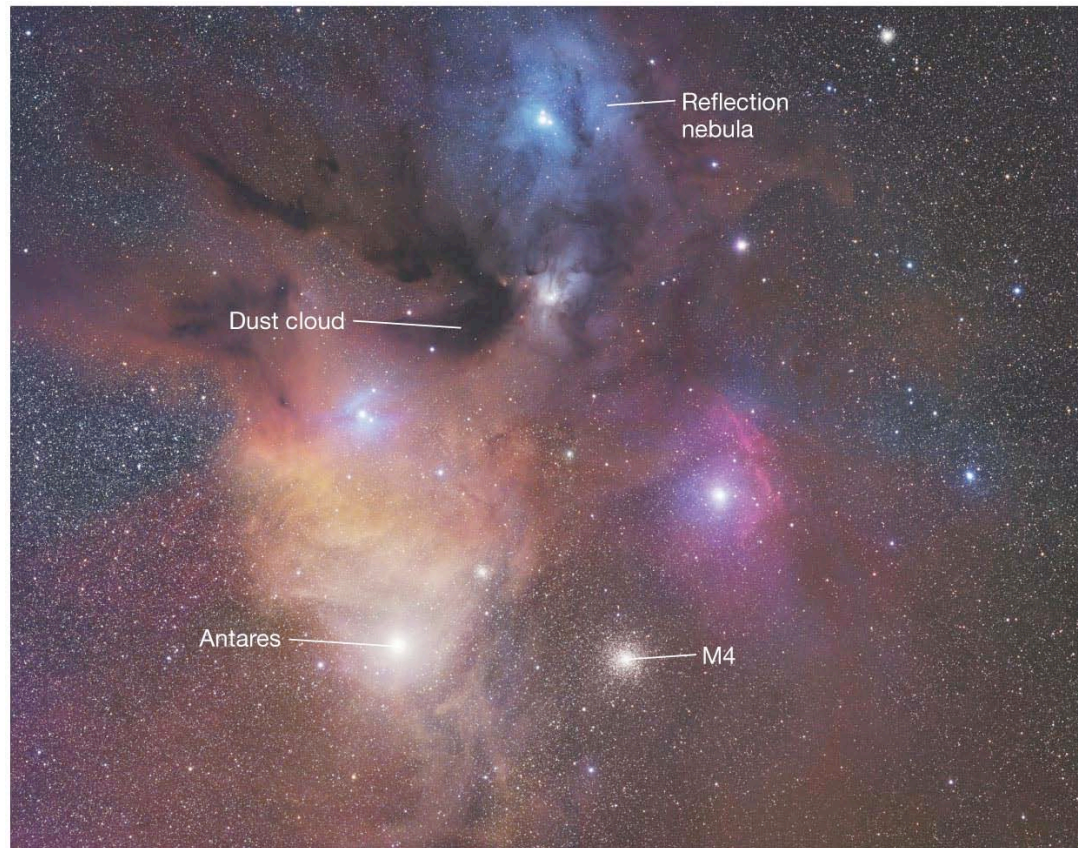


(b)



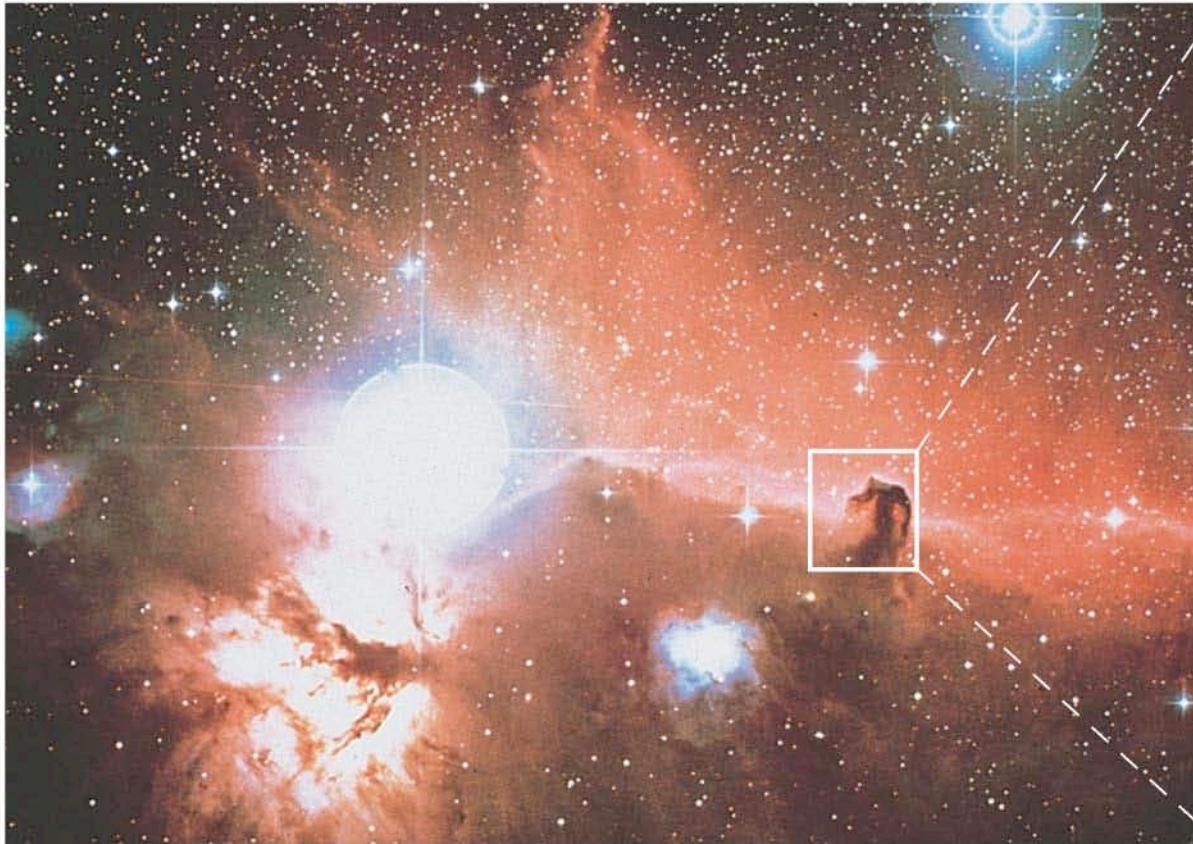
# 18.3 Dark Dust Clouds

The Ophiuchus dust cloud can be seen in this image. Its shape is irregular, with streamers to the upper left:



# 18.3 Dark Dust Clouds

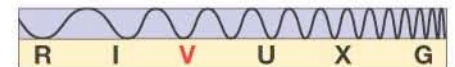
This is the Horsehead Nebula, one of the most famous of dark dust clouds:



(a)



(b)



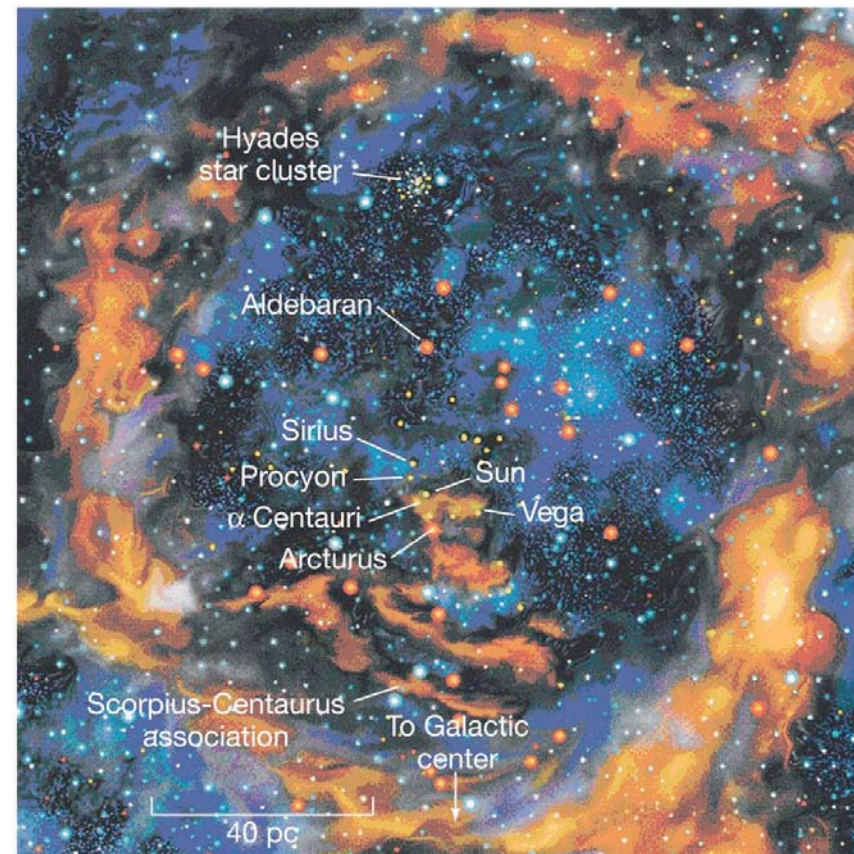


# Discovery 18-1: Ultraviolet Astronomy and the “Local Bubble”

Ultraviolet observations, which must be done from space, have shown that the interstellar medium is full of “bubbles” and “tunnels” that are very hot and have very low densities. The interior is the hot part, emitting UV spectral lines, the outer shell of the bubble is cold, and is observed in neutral hydrogen 21 cm line (yet to come).

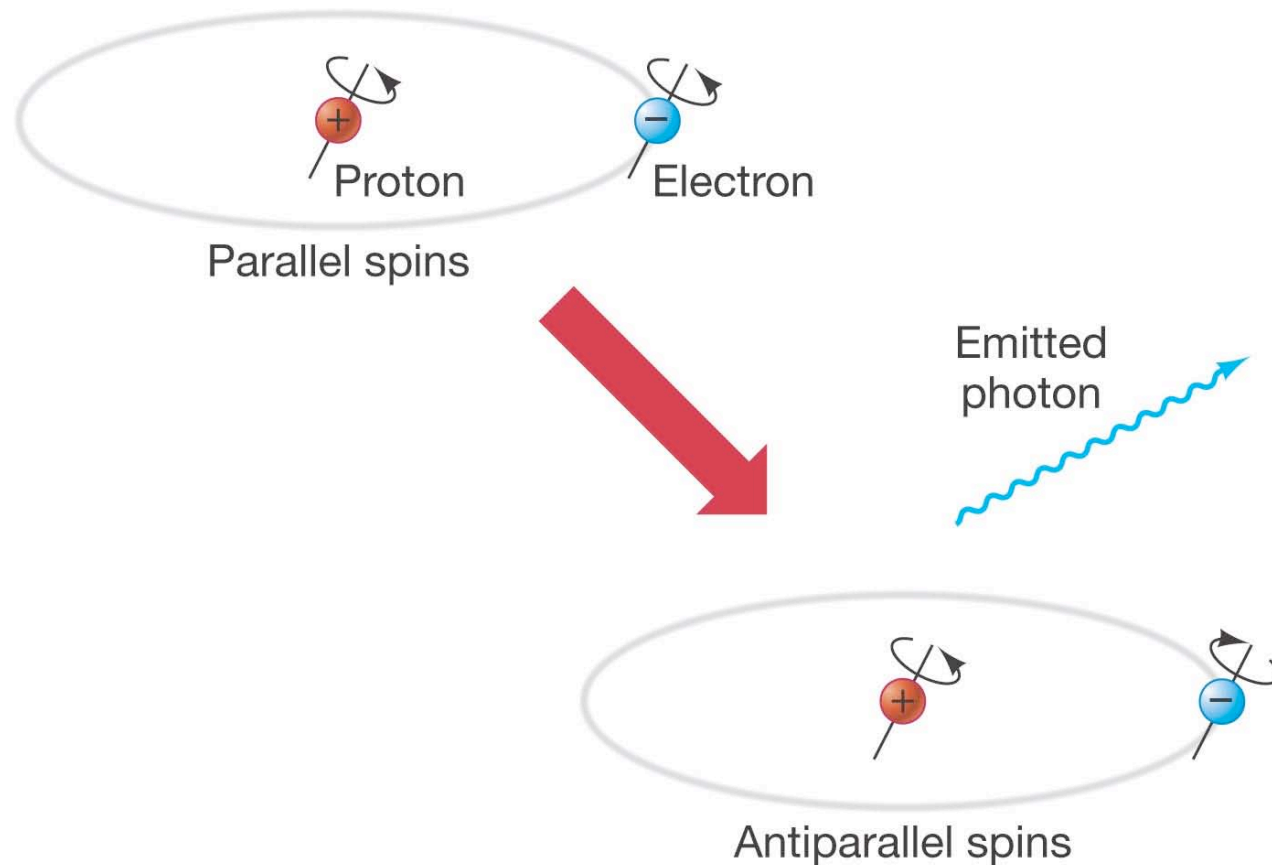
The Sun is within one such “bubble,” about 100 pc across, probably formed by supernova explosions.

This figure is an artist’s impression of the “Local Bubble”. It contains about 200,000 stars:



# 18.4 21-Centimeter Radiation

Interstellar gas emits low-energy radiation, due to a “spin flip” transition in the neutral hydrogen atom. Energy involved is tiny, so resulting spectral line is in the radio part of the spectrum.



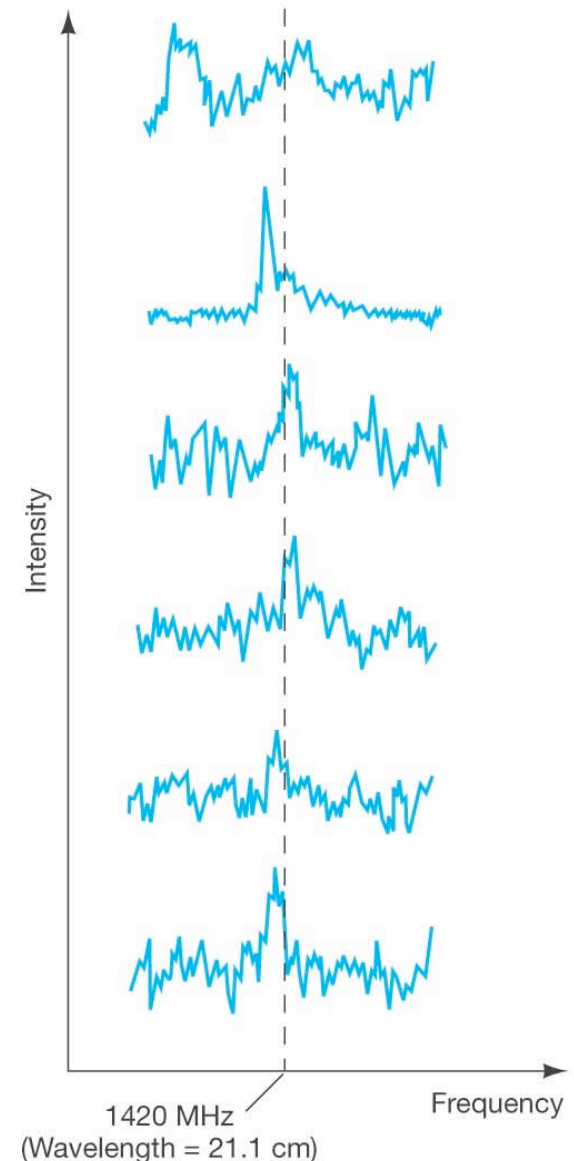
# 18.4 21-Centimeter Radiation

The emitted photon has a wavelength of 21 centimeters, which is in the radio portion of the electromagnetic spectrum.

Actual 21-cm spectra are complex, as the lines are Doppler shifted and broadened (see spectra to the right).

This is the most important spectral line for mapping our own galaxy (the Milky Way): It is at radio wavelengths, so no extinction from dust; and there is lots of hydrogen everywhere, so strong line. It shows us where clouds and shells of gas are, and how they are moving.

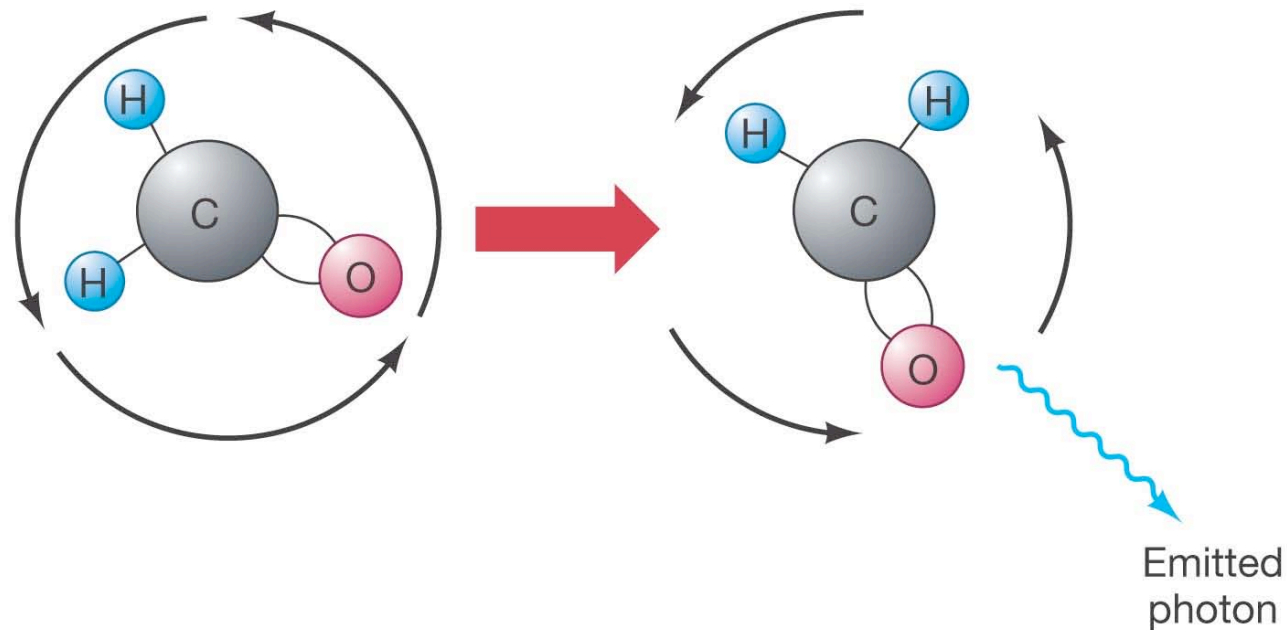
Example: This is how we know that the shells around the “bubbles” discussed earlier are expanding.



# 18.5 Interstellar Molecules

The densest gas clouds are also very cold, around 20 K. These clouds tend to contain molecules, rather than atoms.

Transitions between rotation states of a molecule emit radio-frequency photons:



# 18.5 Interstellar Molecules

Fortunately, radio waves are not absorbed much, so molecular gas clouds can be detected even though there may be other gas and dust clouds in the way.

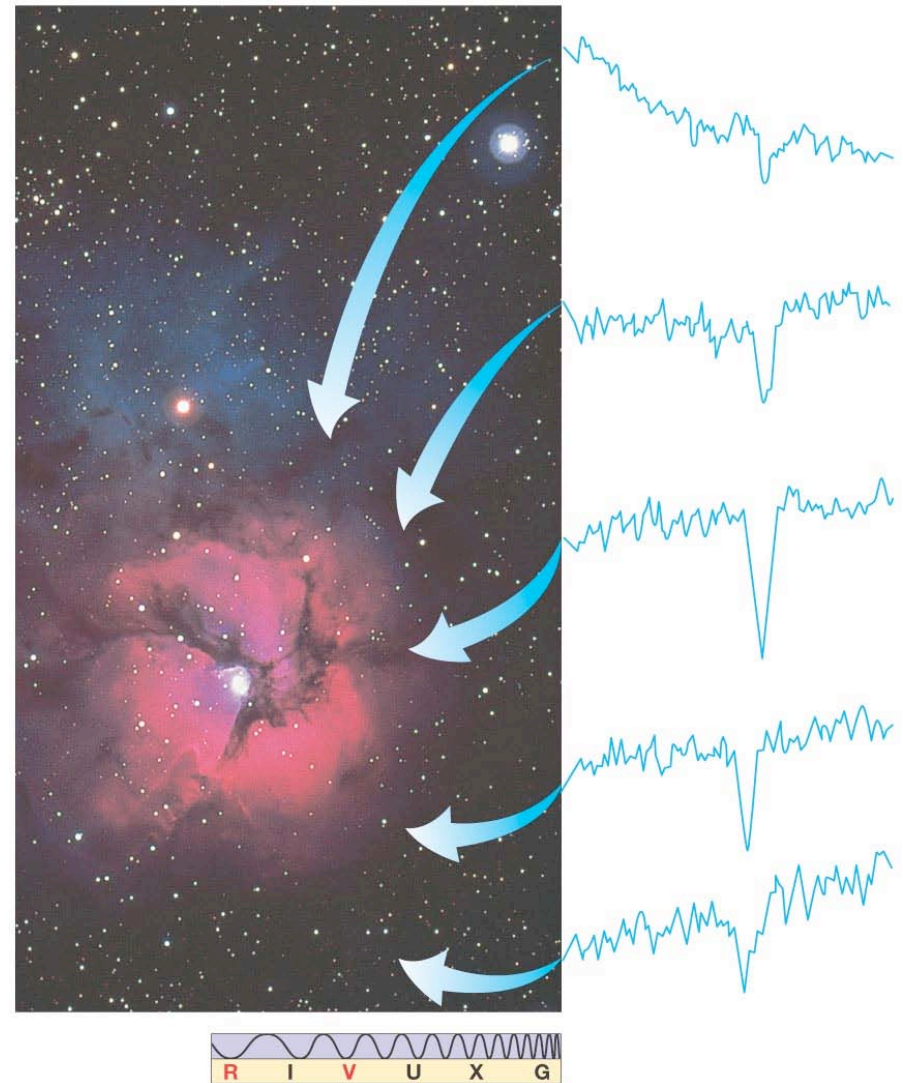
These clouds are **mostly molecular hydrogen**, which unfortunately does not emit in the radio portion of the spectrum.

Other molecules present include: CO, HCN, NH<sub>3</sub>, H<sub>2</sub>O, CH<sub>3</sub>OH, H<sub>2</sub>CO, and more than a hundred others. (See notes accompanying slides for a table in case you are curious; some are from fairly complex organic molecules.)

Molecular clouds are molecular because they are also dark clouds, i.e. they are dense enough that the dust they contain can keep out most of the UV radiation from the rest of the Galaxies.

# 18.5 Interstellar Molecules

Here are some formaldehyde ( $\text{H}_2\text{CO}$ ) absorption lines from different parts of the emission nebula M20:

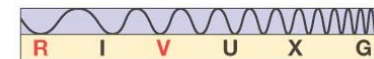
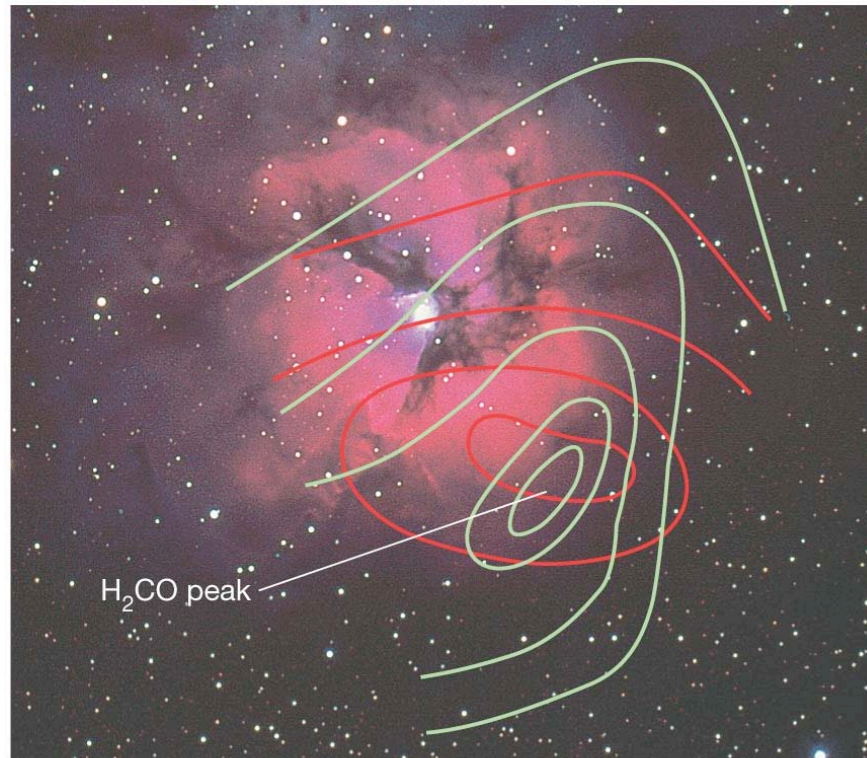


# 18.5 Interstellar Molecules

This is a contour map of  $\text{H}_2\text{CO}$  near the M20 nebula. Other molecules that can be useful for mapping out these clouds are carbon dioxide and water.

The *most* useful is carbon monoxide  $\text{CO}$ . It is abundant, and levels are easily excited at the temperatures of molecular clouds.

Here, the red and green lines correspond to different rotational transitions:



# Summary of Chapter 18

- The interstellar medium is made up of cold gas and small dust grains
- Dust preferentially absorbs shorter wavelengths, causing reddening
- Dust can also completely block light.
- Dust grains must be elongated, as they polarize light
- Emission nebula: Gas that glows on its own, surrounding hot star
- Dark dust clouds can be studied by the absorption lines they produce
- Cold gas clouds can be observed using the hydrogen 21-centimeter line
- Molecular clouds can be observed by the radiation from molecular rotational transitions